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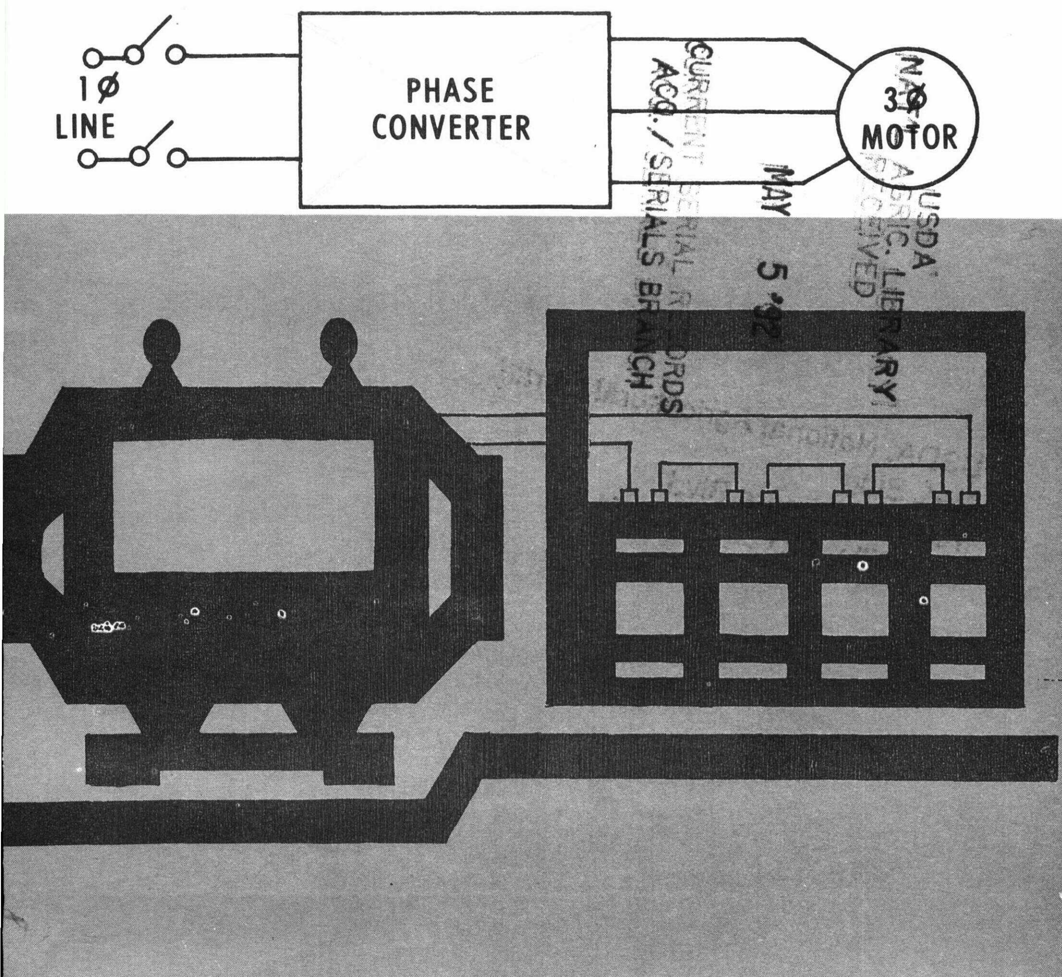
# PHASE CONVERTERS for OPERATION of THREE-PHASE MOTORS from SINGLE-PHASE POWER



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# PHASE CONVERTERS for OPERATION of THREE-PHASE MOTORS from SINGLE-PHASE POWER

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Electric motors are used for many jobs on the farm. They are an efficient, compact, and dependable source of power.

Single-phase motors are in general use because farm electric power service is usually single phase. For some jobs, however, three-phase motors can be a better choice than single-phase motors. Also, they may be the only type readily available in the size needed.

Phase converters make it possible to operate three-phase motors from single-phase power lines when three-phase power is not available. They convert the single-phase line voltage into three-phase voltage.

Proper selection, installation, and protection of both the phase converter and the three-phase motors are essential for satisfactory performance from a converter-motor combination.

Converter-motor combinations are being used to successfully operate many kinds of farm loads. Some examples are crop driers, grain handling systems, irrigation pumps, and animal feeding systems (fig. 1).

## Advantages of Three-Phase Motors

Three-phase motors are used instead of single-phase motors for a number of reasons when three-phase power service is available.

In the larger sizes (above 2-horsepower), the motors generally are more readily available and less expensive than single-phase motors of the same horsepower rating. Also, they are usually smaller, lighter, and offer you a greater choice in the type of enclosure and horsepower rating that you can buy.

Three-phase motors are very simple in construction. No starting windings or starting devices (such as internal centrifugal switches) are required. Fewer parts generally mean less maintenance and service problems.

The direction of motor rotation is easily reversed with three-phase motors. You simply interchange the connections to any two of the motor leads to reverse the motor.

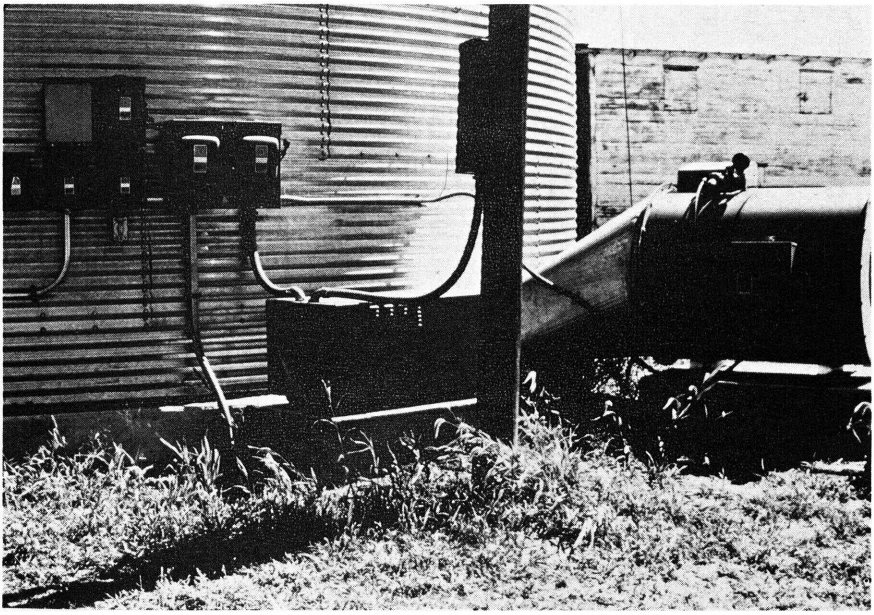

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Figure 1.—Converter-motor combination operating crop drier.

## WHEN TO USE PHASE CONVERTERS

There are three ways to power motor loads:

1. Single-phase motors operating on single-phase power.
2. Phase-converter, three-phase motor combination operating on single-phase power.
3. Three-phase motors operating on three-phase power where the service is available.

Before investing in a phase converter, you need to determine if a converter-motor combination will be the best source of power for your loads.

Draw up a list of your jobs that require electric motors. Include the sizes of motors required, the expected hours of use, and possible future loads. These will be important factors in your decision.

For example, power suppliers often limit the size of motors that may be used on single-phase power lines, because of the high currents that large single-phase motors draw in starting. These high currents reduce the line voltage and may affect service to other customers and equipment.

Converter-motor combinations, however, generally draw less starting current than comparable size single-phase motors (but there is a corresponding decrease

in the starting torque). Consequently, power suppliers may permit the use of higher horsepower converter-motor combinations than single-phase motors on their power lines.

Because the choice of the best method of operation depends on so many factors, you will need to consult with your electric-power supplier, the equipment dealer, and, if possible, phase converter manufacturers. Points to check with them include:

- The cost and availability of single-phase motors and three-phase motors of the required sizes and starting characteristics.
- Motor size limitations on the single-phase power lines.
- The availability and cost of three-phase power service.
- The cost of operation for a converter-motor combination compared with the cost of operation for the other choices. All costs, including the cost of equipment, installation costs, and power rates, should be considered.

Use of a converter-motor combination is often the best choice—

1. When the cost of the line extension to bring three-phase power to your farm is high because of the wire and construction costs for the length of three-phase line required.

2. When the cost per kilowatt-hour for three-phase service is substantially higher than for single-phase service because of the additional investment your power supplier must make to give three-phase service. Over a period of time, the difference in the rates may add up to more than the cost of a converter.

3. When you need to use a large motor, but the starting current of a standard single-phase motor of the required size is too high to use on single-phase lines.

4. When you need temporary three-phase service until regular three-phase service may become available.

5. When you buy equipment with a three-phase motor as an integral part of the unit and replacement of the motor is either too difficult or costs more than a converter.

6. When you need a number of motors and the cost of three-phase motors plus converter is less than the cost of single-phase motors.

## TYPES OF PHASE CONVERTERS

Two general types of converters are available—static and rotary. Each type offers advantages for specific kinds of motor loads.

You can choose the type of converter to use on the basis of the motor loads to be run, but a specific unit should be chosen in consultation with the manufacturer, if possible. Recommendations of the manufacturer are desirable because of the va-

riations in design between the different manufacturers' units. These design differences can make a difference in motor performance, particularly in such important factors as motor starting torque and temperature rise.

Following are general descriptions of the two types of converters.

## Static Converters

Two general kinds of static converters are available—capacitor and autotransformer capacitor. These converters have no moving parts other than switching relays which operate during the starting cycle. Thus, the name static (or nonmoving).

The capacitor converter is the simplest kind of converter. A typical unit, as shown in figure 2, consists essentially of an enclosure, a bank of capacitors, and relays.

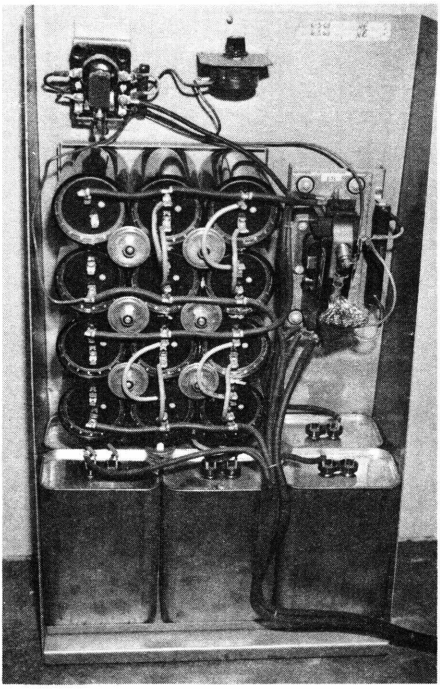

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Figure 2.—Capacitor phase converter.

Figure 3 shows simplified diagrams for two different designs of capacitor converters. In connection (a), two of the three-phase motor terminals are connected directly to the single-phase power lines (through switching and over-current protection in the complete installation). The third motor terminal is connected to one of the single-phase lines through the bank of capacitors of the converter. The capacitors shift the phase (or electrical position) of the voltage to the third winding. The phase-shifted voltage, in combination with the physical position of the motor windings, produces the rotating magnetic field to start and run the motor.

In connection (b), the third motor winding—the one supplied through the capacitor bank—connects to the line, L1, instead of to the common motor winding point as in (a).

Close check must be kept on the loading of motors operated on converters and particularly with the capacitor converter. The currents in the motor windings may exceed the nameplate rating of the motor only for short periods and when air temperatures are favorable for cooling (below 104°F.). Otherwise, the motor

may become overheated and damaged.

Currents drawn by motors operated on capacitor converters may increase rapidly with increases in the motor load. Care must be taken to prevent higher than rated currents when loading the motor above approximately 75 percent of its full-load rating. For some capacitor converters, it may be necessary to limit the motor load to less than the full-load rating of the motor to insure maintaining the currents within the nameplate rating.

An autotransformer-capacitor converter is shown in figure 4. The major difference between this kind of converter and the capacitor converter is the autotransformer unit. The addition of this unit allows the currents in the motor windings to be balanced at full horsepower output.

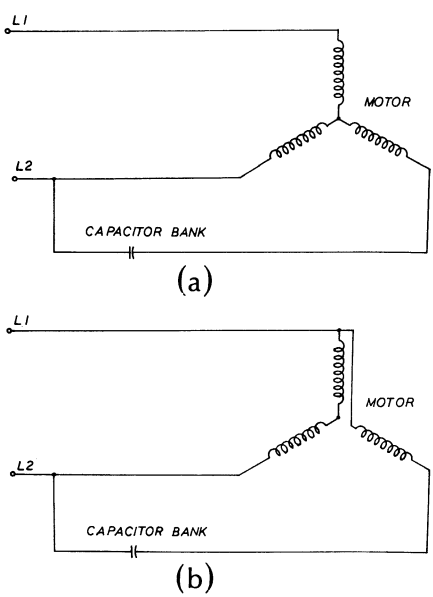

Figure 3.—Simplified diagrams for two designs of capacitor converters.

Figure 5 shows a simplified diagram for an autotransformer-capacitor converter. Two of the three-phase motor terminals are connected directly to the single-phase lines. The third terminal is connected through the capacitor bank to the autotransformer. Taps on the autotransformer make it possible to adjust the voltage supplied to the capacitor bank. This allows the currents in the motor windings to be balanced at a specific load for a given motor.

Motors operated on this kind of converter—as on the capacitor converter—will have less starting torque than if they were operated on regular three-phase power. This must be taken into account when sizing the converter, particularly if the load is hard to start.

More than one motor can be operated at a time on this kind of converter, but the capacitance in the circuit must be changed as the number of motors operated is changed to prevent overheating and damage to the motors. Because this extra care is required, multiple-motor operation is not recommended for this kind of converter unless approved by the manufacturer.

To improve the starting torque of static converters, additional capacitors are connected into the circuit at starting. Electrolytic capacitors are generally used be-

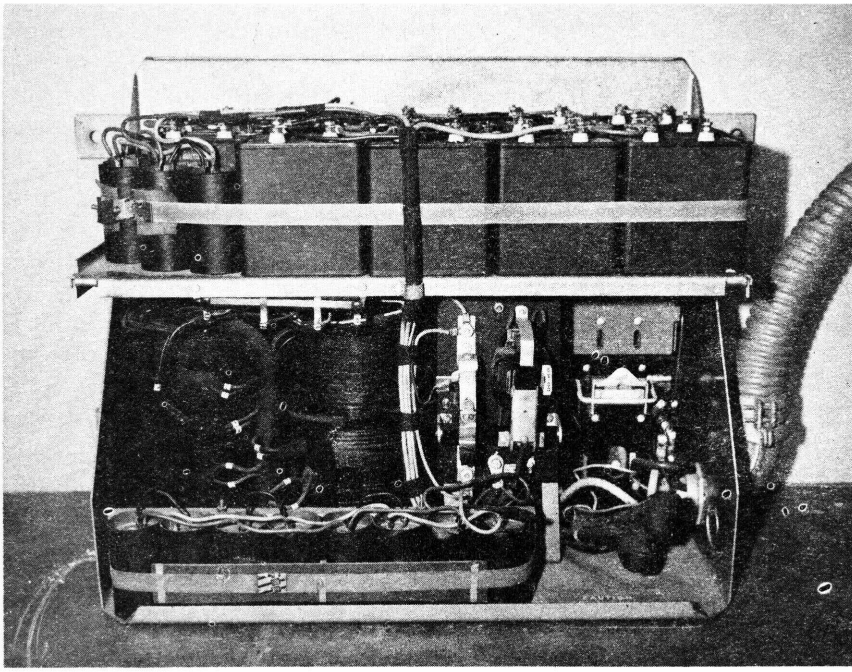

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Figure 4.—Autotransformer-capacitor converter.

cause, for a given capacitance, they are smaller and lower in cost than other types. However, these capacitors have a short duty cycle, or period of operation for which they may be used

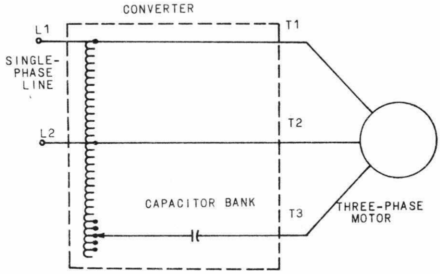


Figure 5.—Simplified diagram for an autotransformer-capacitor converter.

without overheating and failure. This must be considered where motors are started frequently or are slow to reach operating speed. The number of starts per hour or other period must be limited to the manufacturer's recommendation. A typical maximum service rating recommended by one manufacturer is 20 starts per hour of no more than 3 seconds duration for each start.

## Rotary Converters

A rotary converter is shown in figure 6. It consists of a rotating unit similar to a motor

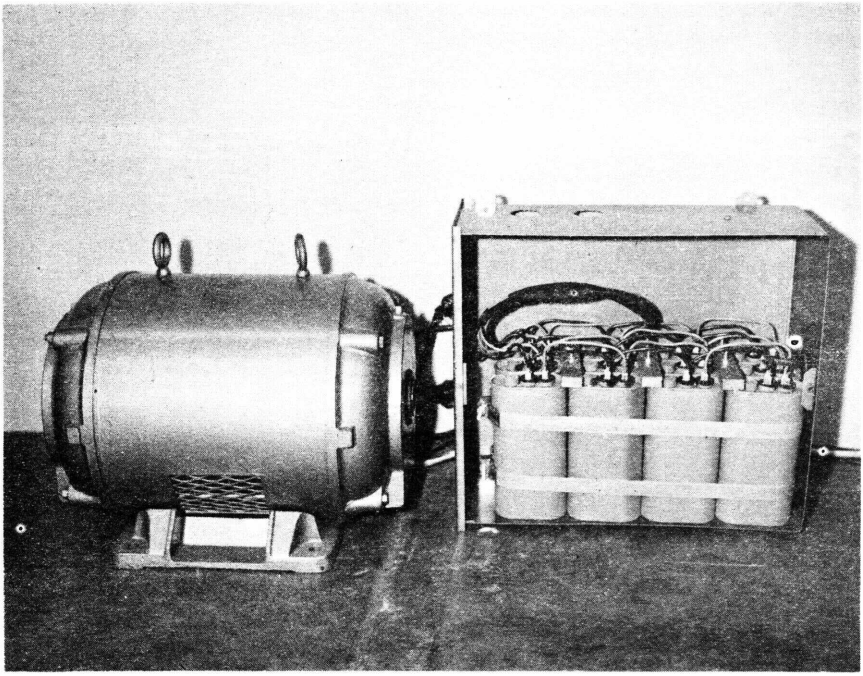

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Figure 6.—Rotary converter.

(on the left) and an enclosure containing capacitors.

Figure 7 shows a simplified diagram for the converter. Two of the three rotating converter terminals are connected directly to the single-phase power lines.

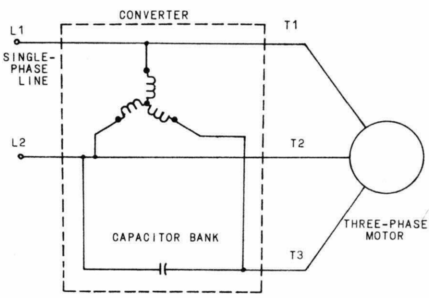


Figure 7.—Simplified diagram for a rotary converter.

The third rotating converter terminal is connected to one of the single-phase lines through the capacitor bank. The capacitors provide the rotating magnetic field to start and operate the converter. The generating action of the rotating converter, in combination with the phase shift of the capacitors, produces the third-phase voltage to operate the motor.

With a rotary converter, you can operate a number of motors under varying load conditions. The converter is started with no load connected. Then, while it is running, motors of sizes up to the rated starting horsepower of the converter may be started

one at a time. The horsepower rating of the largest motor to be started determines the minimum converter rating needed.

The total horsepower load that can be carried by a rotary converter is determined by its design and the method of switching capacitance when motor loads are connected. Generally this will be from two to four times the horsepower of the largest motor that may be started.

The total horsepower rating indicated by the manufacturer should be with the motors fully loaded and operating at the rated temperature. This rating can be exceeded for short periods if air temperatures are favorable for motor cooling or some motors are not fully loaded.

There is also a minimum size of motor that should be operated alone on a rotary converter to prevent overheating of the motor. The size may vary with converters from one-tenth to one-fourth of the converter rating.

Follow the manufacturer's recommendations for both maximum and minimum loading of a converter. Improper loading can result in overheating and damage to motors or the converter.

As with the static converters, the starting and breakdown torques of motors generally are reduced when used with the rotary converter. On some converters, the starting torque for the largest motor operated may be as little as half that obtained if the motor were operated on regular three-phase power. You must allow for this possible reduction in motor torque when selecting a converter for loads requiring high starting torque.

Some rotary converters connect additional electrolytic capacitors into the circuit at starting to increase the starting torque. Up to 80 percent or more of normal motor torque is obtained in this way.

However, as indicted under "Static Converters," page 4 electrolytic capacitors have a short duty cycle. This must be kept in mind when selecting a converter for high inertia loads that start slowly or for loads that require frequent starts. Such loads require special consideration, and you should consult with the converter manufacturer, if possible.

In cold weather, capacitors lose capacitance, and the starting torque of the converter will be less. Also, the starting torque of equipment will be greater because of stiff bearings. The converter and motors must be large enough to provide cold-weather starts.

Additional starting torque may also be obtained by oversizing the converter—using one with a rating greater than that of the largest motor to be started. This will also allow you to increase your motor loads in the future. If you oversize the converter, remember that there is a minimum size of motor that should be operated alone on a converter.

Motor performance may also be improved by adding capacitance to the circuit when larger motors are connected. These capacitors should be sized in accordance with the converter manufacturer's recommendations and connected as indicated in the section on connection of capacitors, page 20.

## CHOICE OF PHASE CONVERTER

Considerations in determining the type of converter to use include: The number of motors to be operated, the kinds of loads and any load variations, the motor torque or turning power required to start and run the loads, and the cost of the converter unit.

Here are some guidelines for selecting a converter:

- For a single fixed load (minimum variation in the load) a capacitor static converter may offer a cost advantage. Allowance must be made for the possible reduction in horsepower available from the motor.
- For a single load that varies over a wide range and for full horsepower output from the motor without exceeding the temperature-rise rating of the motor, consider the autotransformer-capacitor static converter or a rotary converter specifically designed for single motor operation.
- For operation of several motors, the loads of which may vary over a wide range, the rotary converter is probably the best choice. An autotransformer-capacitor static converter could be used, but requires proper switching of capacitors as motors are connected and disconnected and more care in the use and loading of the motors.

*Note:* If the loads are widely spaced or at a distance from the rotary converter, it may be desirable to provide means for turning the converter on from the motor location. Also, if the motors are subject to infrequent automatic starts, make provision for automatic starting of the converter before the motor loads are connected.

Select the size of the converter carefully. It should be chosen to match the characteristics and size of the motor load. The rating for motor starting must be at least as large as the rating of the largest motor to be started. The total-motor-load rating must equal the total motor load to be run at one time.

Oversizing a static converter will result in improper motor operation unless you adjust the converter to the actual load.

Oversizing a rotary converter will result in a slight loss of efficiency. This loss may be unimportant, however, and you may prefer to oversize the converter for improved motor starting torque or to allow for future increase in the motor load.

Undersizing any converter will result in improper motor operation and possibly damage to the converter itself.

# INSTALLATION

Phase converters, like any piece of electrical equipment, should be installed and serviced by an experienced person. Many of the problems reported with these units have been due to improper installation—incorrect connection of the wires to the converter, loose connections, or undersized wiring.

Connection and sizing of the wiring and other installation should be in accordance with the requirements or recommendations of the converter manufacturer, your electric power supplier, and the National and local electrical codes.

The following information is intended as a guide.

## Service Wiring

### *Connection of wiring from converter to motor*

The wiring from the converter to the three-phase motor may be connected in two ways:

1. In the connection shown in figure 8, power is switched to

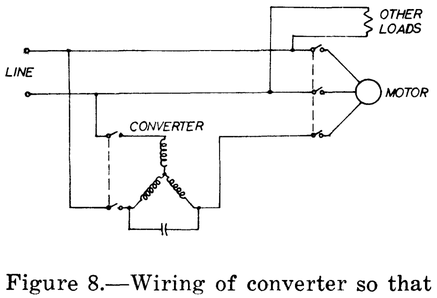


Figure 8.—Wiring of converter so that single-phase power can be supplied to other loads with the converter off.

the converter only. Other loads can be supplied with power from the motor location at all times. The disadvantage of this method is that single-phase power will be applied to the motor if you close the motor switch without the converter turned on. This could damage the motor.

2. In the connection shown in figure 9, power cannot be supplied to the other loads unless the converter has power. While this is a disadvantage, you cannot accidentally apply single-phase power to the three-phase motor.

### *Wire size from converter to motor*

The wiring from the converter to the motor must be of the proper size. If it is too small, there will be excessive voltage drop. This will reduce the motor starting torque, and the motor may not start the load or bring it up to speed. The motor may also draw excessive current and overheat.

You can determine the minimum size of wire that should be used for 230-volt, three-phase motors as follows:

1. First, determine the total motor current that must be supplied on the circuit. For a—

(a) *Single-motor load:* Find the current value for the horsepower rating of the motor from table 1, column 3 (125% full-load amps).

*Example:* Current value for a single 5-horsepower motor is 19 amperes.

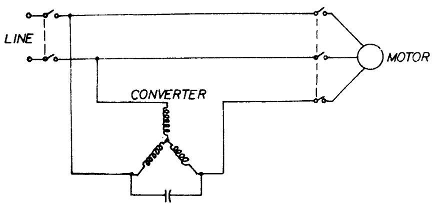


Figure 9.—Wiring of converter so that single-phase power cannot be supplied to other loads unless the converter has power.

(b) *Multiple-motor load:* Find the current value for the largest motor to be used from table 1, column 3 (125% full-load amps). Then find the current value for each additional motor to be used on the circuit from column 2 (full-load amps). Add the values to find the total current requirement.

*Example:* One 10-horsepower motor and one 3-horsepower motor will be used on the circuit. The current value for the larger motor, from column 3, table 1, is 35 amperes. Value for the smaller motor, from column 2, is 9.6 amperes. Total current requirement is 35 + 9.6, or 44.6, amperes.

2. Next, determine the minimum size of wire required to carry the current determined in 1(a) or 1(b) above, according to the type of wire, type of wire insulation, and method of installation. Refer to table 2 for copper wire or table 3 for aluminum wire. If your current value falls between those given in the table, use the next higher value.

*Example:* Copper wire, Type TW and direct burial, will be used to carry the current of 44.6 amperes determined in the example in 1(b) above. That current value is not listed in table 2, so the next higher value, 55, must be used. Minimum size of copper wire required for 55 amperes is number 6.

3. Next, determine the minimum size of wire required to prevent excessive voltage drop for the length of service, or wire run, from the converter to the motor. Refer to table 4 for copper wire or table 5 for aluminum wire. If your current value falls between those listed in the table, use the next higher value.

*Example:* Distance from the converter to the motor is 300 feet. The current value of 44.6 amperes is not listed in table 4 for copper wire, so the next higher value, 45, must be used. Minimum size of wire required to prevent excessive voltage drop is number 2.

4. Choose the larger of the two sizes of wire determined in 2 and 3 above for service from the converter to the motor.

*Example:* Number 2 wire, the size required to maintain the voltage level (in the example in 3 above) is the larger. That size should be used for service to the motor.

### *Wire size from power source to converter*

The wires from the single-phase power source to the converter must also be large enough to prevent excessive voltage drop.

These wires will carry greater current than the wires from the converter to the motor. The single-phase current will be approximately 1½ to 2 times the total current of the motors as determined in 1(a) or 1(b) of the preceding section.

You can determine the minimum size of wire required as follows:

1. First, determine the current value to use for selecting the wire size. For a—

(a) *Single-motor load:* Use twice the current value found for a single-motor load in 1(a) of the preceding section. See column 5 of table 1.

*Example:* Current value for the motor in the example in 1(a) of the preceding section was 19

TABLE 1.—Motor-current values for 230-volt, three-phase motors

| Col. 1 | Col. 2 | Col. 3 | Col. 4 | Col. 5 |
|---|---|---|---|---|
| Motor Horsepower | Full-Load Current Amperes [1] | 125% Full-Load Current Amperes | 150% Full-Load Current Amperes | 250% Full-Load Current Amperes |
| ½ | 2.0 | 2.5 | 3.0 | 5.0 |
| ¾ | 2.8 | 3.5 | 4.2 | 7.0 |
| 1 | 3.6 | 4.5 | 5.4 | 9.0 |
| 1-½ | 5.2 | 6.5 | 7.8 | 13 |
| 2 | 6.8 | 8.5 | 10.2 | 17 |
| 3 | 9.6 | 12 | 14.4 | 24 |
| 5 | 15.2 | 19 | 23 | 38 |
| 7-½ | 22 | 28 | 33 | 56 |
| 10 | 28 | 35 | 42 | 70 |
| 15 | 42 | 52 | 63 | 105 |
| 20 | 54 | 68 | 81 | 136 |
| 25 | 68 | 85 | 102 | 170 |
| 30 | 80 | 100 | 120 | 200 |
| 40 | 104 | 130 | 156 | 260 |
| 50 | 130 | 162 | 195 | 325 |
| 60 | 154 | 192 | 231 | 385 |
| 75 | 192 | 240 | 288 | 480 |
| 100 | 248 | 310 | 372 | 620 |
| 125 | 312 | 390 | 468 | 780 |

[1] Current values taken from table 430-150 of the 1971 National Electrical Code. If motor nameplate current exceeds this value, use nameplate current.

amperes. For sizing the wires from the power source to the converter, use a value of 2 x 19, or 38, amperes. See column 5, table 1.

(b) *Multiple-motor load:* Use twice the current value determined for the largest motor in 1(b) of the preceding section plus 1½ times the current value

TABLE 2.—Allowable current-carrying capacity of insulated copper conductors in amperes.

| | Not more than three conductors in raceway or cable, or direct burial | | Single conductor in free air [1] | |
|---|---|---|---|---|
| Wire size (AWG or MCM) | Rubber type R, RW, RU, and RUW, and thermoplastic type T and TW | Rubber type RH, RHW, and RUH, and thermoplastic type THW and THWN | Thermo-plastic type TW | Weather-proof type WP |
| | Amperes | Amperes | Amperes | Amperes |
| 12 | 20 | 20 | — | — |
| 10 | 30 | 30 | 40 | 55 |
| 8 | 40 | 45 | 55 | 70 |
| 6 | 55 | 65 | 80 | 100 |
| 4 | 70 | 85 | 105 | 130 |
| 3 | 80 | 100 | 120 | 150 |
| 2 | 95 | 115 | 140 | 175 |
| 1 | 110 | 130 | 165 | 205 |
| 0 | 125 | 150 | 195 | 235 |
| 00 | 145 | 175 | 225 | 275 |
| 000 | 165 | 200 | 260 | 320 |
| 0000 | 195 | 230 | 300 | 370 |
| 250 | 215 | 255 | 340 | 410 |
| 300 | 240 | 285 | 375 | 460 |
| 350 | 260 | 310 | 420 | 510 |
| 400 | 280 | 335 | 455 | 555 |
| 500 | 320 | 380 | 515 | 630 |
| 600 | 355 | 420 | 575 | 710 |
| 700 | 385 | 460 | 630 | 780 |
| 750 | 400 | 475 | 655 | 810 |
| 800 | 410 | 490 | 680 | 845 |
| 900 | 435 | 520 | 730 | 905 |
| 1000 | 455 | 545 | 780 | 965 |

[1] Overhead conductors shall not be smaller than number 10 for spans up to 50 feet in length and not smaller than number 8 for longer spans.

determined for each additional motor. See columns 5 and 4, respectively, in table 1.

*Example:* Current value for the larger (10-horsepower) motor in the example in 1(b) of the preceding section was 35 amperes. Value for the smaller (3-horsepower) motor was 9.6 amperes. For sizing the wires

TABLE 3.—Allowable current-carrying capacity of insulated aluminum conductors in amperes.

| | Not more than three conductors in raceway or cable, or direct burial | | Single conductor in free air [1] | |
|---|---|---|---|---|
| Wire size (AWG or MCM) | Rubber type R, RW, RU, and RUW, and thermoplastic type T and TW | Rubber type RH, RHW, and RUH, and thermoplastic type THW and THWN | Thermoplastic type TW | Weatherproof type WP |
| | Amperes | Amperes | Amperes | Amperes |
| 12 | 15 | 15 | — | — |
| 10 | 25 | 25 | 30 | 45 |
| 8 | 30 | 40 | 45 | 55 |
| 6 | 40 | 50 | 60 | 80 |
| 4 | 55 | 65 | 80 | 100 |
| 3 | 65 | 75 | 95 | 115 |
| 2 | 75 | 90 | 110 | 135 |
| 1 | 85 | 100 | 130 | 160 |
| 0 | 100 | 120 | 150 | 185 |
| 00 | 115 | 135 | 175 | 215 |
| 000 | 130 | 155 | 200 | 250 |
| 0000 | 155 | 180 | 230 | 290 |
| 250 | 170 | 205 | 265 | 320 |
| 300 | 190 | 230 | 290 | 360 |
| 350 | 210 | 250 | 330 | 400 |
| 400 | 225 | 270 | 355 | 435 |
| 500 | 260 | 310 | 405 | 490 |
| 600 | 285 | 340 | 455 | 560 |
| 700 | 310 | 375 | 500 | 615 |
| 750 | 320 | 385 | 515 | 640 |
| 800 | 330 | 395 | 535 | 670 |
| 900 | 355 | 425 | 580 | 725 |
| 1000 | 375 | 445 | 625 | 770 |

[1] Overhead conductors shall not be smaller than number 10 for spans up to 50 feet in length and not smaller than number 8 for longer spans.

to the converter, use a value of $2 \times 35$, or 70, $+ 1.5 \times 9.6$, or 14.4, or a total of 84.4 amperes.

2. Next, determine the minimum size of wire required to carry the current determined in 1(a) or 1(b) above, according to the type of wire, type of wire insulation, and method of installation. Refer to table 2 for copper wire or table 3 for aluminum wire. If your current value falls between those listed in the table, use the next higher value.

*Example:* Copper wire, Type TW and direct burial, will be used to carry the current of 84.4 amperes determined in the example in 1(b) above. That current value is not listed in table 2, so the next higher value, 95, must be used. Minimum size of copper wire required for 95 amperes is number 2.

3. Next, determine the minimum size of wire required to prevent excessive voltage drop for the length of service, or wire run, to the converter. Refer to table 4 for copper wire or table 5 for aluminum wire. If your current value falls between those listed in the table, use the next higher value.[1]

[1] Tables 4 and 5 are actually for sizing three-phase wiring, but for simplicity are being used to size the single-phase wiring. Use of the next higher current value partially compensates for possible differences in wire size requirements. For a more conservative estimate of the proper wire size, increase your current value by 16% and then use the closest value in the tables.

*Example:* The distance from the single-phase power source to the converter is 50 feet. The current value of 84.4 amperes determined in 1(b) above is not listed in the table, so the next higher value, 90, must be used. Minimum size of copper wire required to prevent excessive voltage drop for a current of 90 amperes and a length of service of 50 feet is number 6.

4. Choose the larger of the two sizes of wire determined in 2 and 3 above for service from the power source to the converter.

*Example:* Number 2 wire, the size determined in the example in 2 above is the larger. That size should be used from the power source to the converter.

## Overload Protection

Your motors, service and branch circuit wiring, and phase converter should be protected against overload—the drawing of an excessive amount of current. Too much current causes overheating and damage to equipment.

The overload protection should be provided in accordance with the requirements and recommendations of your power supplier, motor and phase converter manufacturers, and the National Electrical Code and local regulations.

The overcurrent protection for motors should have a rating of not more than 125% of the current rating of the motor. If motor fuses are used, they should

TABLE 4.—Copper wire size required at 230-240 volts, three-phase, based on 2% voltage drop.

| Load in amperes | Length of wire run in feet | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
| | Wire Size (AWG or MCM)[1] | | | | | | | | | | | | | | | | |
| 5.0 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 10 | 8 | 8 |
| 7.5 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 8 | 8 | 8 | 8 | 6 |
| 10.0 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 10 | 8 | 8 | 8 | 6 | 6 | 6 | 6 |
| 15.0 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 8 | 8 | 8 | 6 | 6 | 6 | 6 | 4 | 4 | 4 |
| 20.0 | 12 | 12 | 12 | 10 | 10 | 8 | 8 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 3 | 3 |
| 25.0 | 12 | 12 | 10 | 10 | 8 | 8 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 2 |
| 30.0 | 12 | 12 | 10 | 8 | 8 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 3 | 2 | 2 | 2 | 1 |
| 35.0 | 12 | 10 | 10 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 1 |
| 40.0 | 12 | 10 | 8 | 8 | 6 | 6 | 4 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 |
| 45.0 | 12 | 10 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 0 |
| 50.0 | 12 | 10 | 8 | 6 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 1 | 1 | 0 | 0 | 00 | 00 |
| 55.0 | 12 | 8 | 8 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 00 |
| 60.0 | 12 | 8 | 6 | 6 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 00 | 00 | 000 |
| 70.0 | 10 | 8 | 6 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 00 | 00 | 000 | 000 | 000 |
| 80.0 | 10 | 8 | 6 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 00 | 00 | 000 | 000 | 0000 | 0000 |
| 90.0 | 10 | 6 | 6 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 |
| 100.0 | 10 | 6 | 4 | 4 | 3 | 2 | 1 | 1 | 0 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 250 |
| 115.0 | 8 | 6 | 4 | 3 | 2 | 1 | 1 | 0 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 250 | 300 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **130.0** | **8** | **6** | **4** | **3** | **2** | **1** | **0** | **0** | **00** | **00** | **000** | **0000** | **0000** | **250** | **300** | 300 | 350 |
| **145.0** | **8** | **4** | **3** | **2** | **1** | **0** | **0** | **00** | **00** | **000** | **0000** | **0000** | **250** | **300** | **300** | 350 | 350 |
| **160.0** | **8** | **4** | **3** | **2** | **1** | **0** | **00** | **00** | **000** | **000** | **0000** | **250** | **300** | **300** | 350 | 350 | 400 |
| 175.0 | 6 | 4 | 3 | 1 | 0 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 300 | 350 | 350 | 400 | 500 |
| 200.0 | 6 | 4 | 2 | 1 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 300 | 350 | 400 | 400 | 500 | 500 |
| 225.0 | 6 | 3 | 2 | 0 | 00 | 00 | 000 | 0000 | 0000 | 250 | 300 | 350 | 400 | 400 | 500 | 500 | 600 |
| 250.0 | 6 | 3 | 1 | 0 | 00 | 000 | 0000 | 0000 | 250 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 600 |
| 275.0 | 4 | 2 | 1 | 00 | 000 | 000 | 0000 | 250 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 600 | 700 |
| 300.0 | 4 | 2 | 0 | 00 | 000 | 0000 | 0000 | 250 | 300 | 300 | 400 | 500 | 500 | 600 | 600 | 700 | 750 |
| 350.0 | 4 | 1 | 0 | 000 | 0000 | 0000 | 250 | 300 | 350 | 350 | 500 | 500 | 600 | 700 | 700 | 800 | 900 |
| 400.0 | 4 | 1 | 00 | 000 | 0000 | 250 | 300 | 350 | 400 | 400 | 500 | 600 | 700 | 750 | 800 | 900 | 1000 |
| 450.0 | 3 | 0 | 00 | 0000 | 250 | 300 | 350 | 400 | 400 | 500 | 600 | 700 | 750 | 800 | 900 | 1000 | |
| 500.0 | 3 | 0 | 000 | 0000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 800 | 900 | 1000 | | |
| 550.0 | 2 | 00 | 000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 800 | 900 | 1000 | | | |
| 600.0 | 2 | 00 | 0000 | 250 | 300 | 400 | 500 | 500 | 600 | 600 | 750 | 900 | 1000 | | | | |

[1] AWG = American Wire Gage, and MCM = thousand circular mils.

Wire sizes are based on *voltage drop only*. Table 2 must be referred to at the current value used to check the minimum wire size for proper current carrying capacity and the larger of the two sizes used.

Wire in overhead spans must also have adequate mechanical strength and should not be smaller than number 10 for spans up to 50 feet or smaller than number 8 for spans greater than 50 feet.

TABLE 5.—Aluminum wire size required at 230-240 volts, based on 2% voltage drop.

| Load in amperes | Length of wire run in feet | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
| | Wire size (AWG or MCM)[1] | | | | | | | | | | | | | | | | |
| 5.0 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 8 | 8 | 8 | 8 | 6 | 6 |
| 7.5 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 6 | 4 |
| 10.0 | 12 | 12 | 12 | 12 | 10 | 10 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 4 |
| 15.0 | 12 | 12 | 10 | 10 | 8 | 8 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 3 | 3 | 3 | 2 |
| 20.0 | 12 | 12 | 10 | 8 | 8 | 6 | 6 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 1 |
| 25.0 | 12 | 10 | 8 | 8 | 6 | 6 | 4 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 |
| 30.0 | 12 | 10 | 8 | 6 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 0 | 00 |
| 35.0 | 12 | 8 | 8 | 6 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 00 |
| 40.0 | 12 | 8 | 6 | 6 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 000 |
| 45.0 | 10 | 8 | 6 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 000 | 0000 |
| 50.0 | 10 | 8 | 6 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 00 | 00 | 000 | 000 | 0000 | 0000 |
| 55.0 | 10 | 6 | 6 | 4 | 3 | 3 | 2 | 1 | 1 | 0 | 0 | 00 | 000 | 000 | 0000 | 0000 | 0000 |
| 60.0 | 10 | 6 | 4 | 4 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 0000 | 0000 | 0000 | 250 |
| 70.0 | 8 | 6 | 4 | 3 | 2 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 0000 | 0000 | 250 | 250 | 300 |
| 80.0 | 8 | 6 | 4 | 3 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 0000 | 0000 | 250 | 300 | 300 | 350 |
| 90.0 | 8 | 4 | 3 | 2 | 1 | 0 | 0 | 00 | 00 | 000 | 0000 | 0000 | 250 | 300 | 300 | 350 | 350 |
| 100.0 | 8 | 4 | 3 | 2 | 1 | 0 | 00 | 00 | 000 | 000 | 0000 | 250 | 300 | 300 | 350 | 350 | 400 |
| 115.0 | 6 | 4 | 2 | 1 | 0 | 00 | 00 | 000 | 000 | 0000 | 250 | 300 | 300 | 350 | 400 | 400 | 500 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130.0 | 6 | 4 | 2 | 1 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 300 | 350 | 400 | 500 | 500 | 500 |
| 145.0 | 6 | 3 | 1 | 0 | 00 | 000 | 000 | 0000 | 0000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 600 |
| 160.0 | 6 | 3 | 1 | 0 | 00 | 000 | 0000 | 0000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 600 | 700 |
| 175.0 | 4 | 2 | 1 | 00 | 000 | 000 | 0000 | 250 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 700 |
| 200.0 | 4 | 2 | 0 | 00 | 000 | 0000 | 250 | 300 | 300 | 350 | 400 | 500 | 600 | 600 | 700 | 700 | 800 |
| 225.0 | 4 | 1 | 0 | 000 | 0000 | 250 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 750 | 800 | 900 |
| 250.0 | 4 | 1 | 00 | 000 | 0000 | 250 | 300 | 350 | 400 | 400 | 500 | 600 | 700 | 750 | 800 | 900 | 1000 |
| 275.0 | 3 | 0 | 00 | 0000 | 250 | 300 | 350 | 350 | 400 | 500 | 600 | 700 | 700 | 800 | 900 | 1000 | |
| 300.0 | 3 | 0 | 000 | 0000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 800 | 900 | 1000 | | |
| 350.0 | 2 | 00 | 000 | 250 | 300 | 350 | 400 | 500 | 500 | 600 | 700 | 800 | 900 | 1000 | | | |
| 400.0 | 2 | 00 | 0000 | 300 | 350 | 400 | 500 | 600 | 600 | 700 | 800 | 900 | | | | | |
| 450.0 | 1 | 000 | 250 | 300 | 400 | 500 | 500 | 600 | 700 | 750 | 900 | 1000 | | | | | |
| 500.0 | 1 | 000 | 250 | 350 | 400 | 500 | 600 | 700 | 750 | 800 | 1000 | | | | | | |
| 550.0 | 0 | 0000 | 300 | 350 | 500 | 600 | 700 | 700 | 800 | 900 | | | | | | | |
| 600.0 | 0 | 0000 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | | | | | | | |

[1] AWG = American Wire Gage, and MCM = thousand circular mils.

Wire sizes are based on *voltage drop only*. Table 3 must be referred to at the current value used to check the minimum wire size for proper current carrying capacity and the larger of the two sizes used.

Wire in overhead spans must also have adequate mechanical strength and should not be smaller than number 10 for spans up to 50 feet or smaller than number 8 for spans greater than 50 feet.

be the dual-element type and may be the next larger available size.

The overcurrent protection for the single-phase wiring to the converter should have a rating in accordance with the size of wiring chosen in the service wiring section under "Installation," page 10. This may not provide adequate protection for the converter, particularly in multiple-motor installations. The converter manufacturer should be consulted for his recommendations for overcurrent protection of the converter.

With static converters, the recommended overload protection may not allow the use of full horsepower from the motor. But, as indicated in the section on this type of converter (page 4), the load should be limited to prevent excessive currents and damage to the motor.

## Magnetic Starters

Magnetic starters are a combination of a magnetic controller, or relay, and overload protection for the motor. Use of one for each motor is highly recommended and may be required by many power suppliers.

It is essential to use a magnetic starter with a rotary converter to provide the means of disconnecting the motors in case of power interruption. Otherwise, when power is restored, the motors will try to start on single-phase power before the converter reaches operating speed and may be damaged.

For maximum protection of the motors, use magnetic starters that have thermal overload protection in each line.

## Connection of Capacitors

As indicated in the section on "Types of Phase Converters," page 3, capacitors may be added to the circuit as additional motors are connected to improve motor performance. These capacitors must be connected between the contacts and heaters as shown in figure 10, so that they will be disconnected when the motor is disconnected. Unless some capacitance is removed from the circuit as larger motors are disconnected, small motors operating on the converter will have badly unbalanced voltages

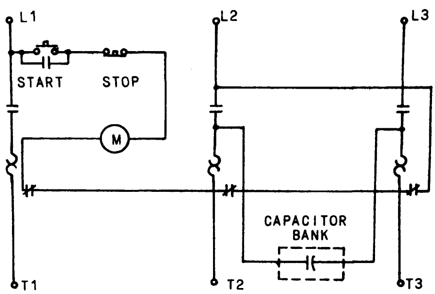


Figure 10.—Proper connection of extra capacitance into the circuit.

and most likely will overheat. In some cases, the converter may also overheat and be damaged.

When capacitor banks are connected as shown in figure 10, their current will not flow through the heater coils of the starter. This will help prevent false tripouts of the starter.

Consult the phase converter manufacturer for the recommended value of capacitance and method of connection to be used for multiple motor loads.

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